FUEL MODEL AND FOREST TYPE MAPPING FOR FARSITE™ INPUT

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ABSTRACT

A methodology is outlined for mapping Fuel Model Indexes/Forest Types (FMI/FT), to provide input for the fire area simulator FARSITE. USGS Digital Orthophoto Quads, together with contour and stream themes from USGS topographic maps, were digitally combined into a "TopoPhoto." Photo-interpretation and ground-truthing of perceived FMI/FT polygons on the Walhalla Plateau were completed during the fall of 1998. "TopoPhotos" will greatly aid mapping the rest of the North and South Rims of Grand Canyon National Park (more than 150,000 acres) in the summer of 1999. This mapping data will then be input as Landscape Files for FARSITE, in the fall of 1999.

Keywords: fire, modeling, GIS, restoration, ground-truthing

INTRODUCTION

This paper is intended to inform interested readers about the role of computer mapping, modeling, and simulation in prescribed fires, as used in the restoration of the forested ecosystem of Grand Canyon National Park. The park, known well for the exceptional length of recorded geologic history, is less well-known in terms of its ecologic history. The National Park Service, mandated to "preserve for future generations...," has recognized that its decadal history of fire suppression, however benignly intended, has wrought significant impact upon much of the land it is charged with maintaining. Grand Canyon National Park is currently in the process of assessing appropriate means of restoring its forests to a pre-settlement condition. Prescribed fire management is one of the techniques uniquely suited to reintroduce fire into the forested ecosystem process. One of the tools available to prescribed fire managers is a fire area growth simulator. FARSITE is a model for "spatially and temporally simulating the spread and behavior of fires under conditions of heterogeneous terrain, fuels, and weather" (Finney M., 1997). The scope of this paper will be limited to our means of providing the "spatial" dimension to the simulation.

Site Location

Grand Canyon National Park is located in northern Arizona, along both sides of the Colorado River, and is bounded by northern latitudes 35 to 37 degrees, and western longitudes 111 to 114 degrees. This paper details the findings from a pilot project on the Walhalla Plateau, in the eastern portion of what is popularly referred to as the North Rim, in the northeast corner of the Grand Canyon National Park. These findings will later form the basis for vegetative modeling of the remainder of the Park, as the Walhalla Plateau's range of vegetation nearly encompasses that of the North Rim.

Site Description

Grand Canyon National Park is located in northwest Arizona in the southwestern edge of the Colorado Plateau, incised by the Colorado River. The resulting canyon separates the Kaibab Plateau to the north from the Coconino Plateau to the south. Elevations vary from 9100' in the north, to 1000' along the river, to 6100' along the Coconino Plateau. The Walhalla Plateau ranges from 7800' to 8600' in elevation, and is characterized by vegetation that has evolved since the Late Pleistocene epoch.

Climate

Taush (1999) summarized the identifiable climatic periods and general associated vegetation changes from the Late Pleistocene through the Holocene for the Great Basin, and an adaptation including the Kaibab Plateau follows:

Late Pleistocene [11,500 BP (Before Present)] Semi-arid woodlands were 1000m lower in vegetation, with pinyon woodlands and mixed conifer and ponderosa pine forests 500-600 km farther south than at present.

Early Holocene [11,500 to 8,000 BP] Pinyon-juniper woodlands and adjacent forests began northward movement.

Mid-Holocene Warm Period [8,000 to 5,500 BP] Pinyon-juniper woodlands were 300-5500m higher in elevation than today, with pine and grass species decreasing.

Transition Period [5,500 to 4,500 BP] A gradual increase in precipitation, with continued northward migration of pinyon/juniper and other conifers.

Neoglacial [4,500 to 2,500 BP] Much cooler and wetter than the Mid-Holocene, lowering the upper tree line, and substantially increasing the range of woodlands at mid- to low elevations.

Post-Neoglacial Drought [2,500 to 1,300 BP] A significant drop in precipitation, diminished woodland presence, and increased erosion.

Medieval Warm Period [1,300 to 900 BP] Increased precipitation, bimodally between winter and summer, and a re-expansion of woodlands northwards.

Transitional Dry Period [900 to 550 BP] Winter-dominant dry period accompanied by lower temperatures, with a decline in tree and grass dominance, and a decrease in the range of tree distribution.

Little Ice Age [550 to 150 BP] A cooler and much wetter period, with the lowest tree-lines since the Early Holocene, with gradual re-expansion of the pinyon-juniper woodlands. Woodlands in general were much more open than at present. Higher fire frequencies than today, with different forest composition and structure than at present.

Historical Period [150 BP to Present] Change in climate is inextricably interwoven with the influence of historical settlement and livestock grazing, a decrease in wildfire frequency, increase in atmospheric CO2 levels, and rapid increases in woodland density (possibly to the highest levels of the Holocene).

Existing palynology and midden analysis adjacent to the Grand Canyon generally supports the above characterization. Pollen analysis (see Figure 1) by Shafer (1989), from Crane Lake about 15 miles to the north, suggest a northward expansion from both the shadscale steppe community (including pinyon-juniper and ponderosa pine forests, from the palynology record duration of 11,000 years BP [Before Present], through the year 4240 BP – see Figure 1). This reflects the presence of a predicted intensified monsoon circulation at 9000 years BP (Betancourt and Devender, 1984). Subsequently, a diminishing monsoonal intensity from

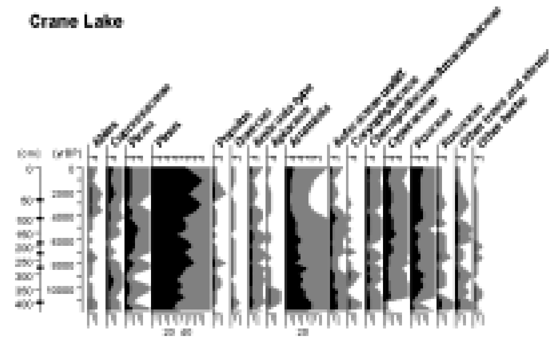

Figure 1. Pollen analysis of Crane Lake.

7000 years may have eliminated *Pinus ponderosa* (a summer rainfall indicator) from its lower elevational range (Shafer, D., 1989), permitting *Pinus edulis* an expanding ecotone. With but a brief increase in Crane Lake levels around 4240 year BP, the diminishing monsoonal intensity continues to the present. Palynology by Weng and Jackson (1999) from Fracas Lake and Bear Lake (2-3 miles north of the park's northern boundary) are more complete; reflect more current palynological technologies; and generally support findings by Shafer (1989) and the midden analysis by Cole (1982). Adding significantly to Shafer's analysis, Weng and Jackson (1999) found that "Mixed forests of *Picea* (mainly *P. pungens* (Colorado spruce)), *Abies lasiocarpa* (subalpine fir), *Pinus ponderosa*, and *Pseudotsuga* (Douglas fir) grew near Bear Lake for the remainder of the Holocene (after ~8,000 calendar year BP). *Picea engelmannii* populations re-expanded near Bear Lake after 4,000 cal yr BP. Charcoal records indicate that fire probably helped *Pinus ponderosa* to become established near Bear Lake." Weng and Jackson (1999) concluded that the "increase of fire incidence after 10,600 cal yr BP probably resulted from establishment of Pinus ponderosa. Climatic warming and perhaps greater season drought contributed to the increase in fires."

Midden analysis supports this with the "reduction in summer precipitation in the eastern Grand canyon between 8500 and 5000 years BP…suggested by the upward displacement of *Pinus ponderosa* macrofossils in middens at comparable elevations…earlier" (Cole, 1982).

Pre-Settlement History

Prior to European/American settlement, the vegetation evolving from climatic trends was primarily affected by the introduction of fire, either weather-caused (lightning) or introduced by indigenous peoples. Lightning associated with summer monsoonal activity was thought to be a primary source (Wolf and Mast, 1998). Nationally, there is speculation that prior indigenous peoples had a significant influence on pre-settlement landscapes and were a keystone of the ecosystem structure. Locally, Paiute and Navajo tribes "prescribed" fire for hunting and agricultural endeavors. In both cases, it is reasonable to assume that, while neither, as "ignition sources," were entirely random, the frequency of ignition would have been relatively often and the intensity relatively low. Over sufficient time, a patchwork mosaic of vegetation would have developed, particularly with landscapes suitable for agricultural sites.

Post-settlement History

With the arrival of Mormon settlers in the 1870's, the introduction of grazing further affected the vegetative mosaic. Thought to be a "natural" solution to the frequent, but low-intensity fires, sheep, then cattle, were "put to pasture," both to take "fuel from the fire" as well as to "fatten the stock."

Tree ring records in this region extend back to this era. From the frequent but low-intensity fires recorded for centuries prior, the nearly complete absence of fires after this date point to the effectiveness of the early settlers' strategies. Add those strategies to the advent of National Park status in 1919 and the fire suppression that was commensurate with the time, and a decades-long history of intervention in the natural fire regime prevailed.

Current Site Condition

Decades of active fire suppression (1919-1989), as practiced by most resource and land management agencies, has promoted unnatural conditions in forests across the nation. In many agencies, the practice of harvesting timber from their lands has diminished the threat that a continuous dense accumulation of "fuels" provides. The National Park Service mission precludes such commercial practices, and is faced with a significant threat of catastrophic fire. In little over a century, Grand Canyon National Park's forests have gone from a natural fire regime of high frequency and low intensity to an unnaturally suppressed fire regime that is increasingly of lower frequency, and higher intensity.

METHODS

Cartographic Base Selection

Satellite imagery is well suited for resource management across a broad landscape, particularly with Thematic Mapper™ imagery, with its balanced compromise between spatial resolution and computational efficiencies. Though used extensively and often cited for its spectral resolution (6 bands in the visible spectrum, 1 band in the thermal spectrum) across broad landscapes, Thematic Mapper™ imagery effectively has a minimum mapping unit of 900 square meters, and is best suited for relatively homogeneous vegetation. Additionally, extensive field work is required to verify vegetative imagery classification.

It was felt that Grand Canyon National Park, with a smaller landscape than most of those using TM imagery, could benefit from the use of co-registered digital imagery available from the United States Geological Survey (USGS) in the form of black-and- white Digital Orthophoto Quarter Quads (DOQQ's).

Scanned USGS Topographic Map Quads (or Digital Raster Graphics – DRGs, see Figure 4) were used as a cartographic base, once they were digitally combined with USGS DOQQs (see Figure 5, combined with Figure 4, following body of text). This combination placed topographic themes (administrative boundaries, state plane coordinates and UTM grids, hydrography, roads, site names, and topographic contours) over the orthophoto, and provided an excellent cartographic base (see Figure 6, following body of text).

Photo-interpretation

Initial photo-interpretation was done with DOQQs. The forested area of the Walhalla Plateau was first broken up into discrete homogeneous groups, based on perceived textural cues (coarse to fine), density (open to closed canopy), and to some extent reflectance values (gray-scale differences). These discrete homogenous groups were delineated into an Arc/Info environment as polygons, with the following attribute fields: Fuel Model Index, Crown Height, Crown Base Height, Crown Bulk Density, Crown Closure, Shrub Height, and Vegetation Classification (see Field Data Collection Sheet in Figure 3, on following page). All attributes were determined, or derived, from extensive field-verified data collection.

Data Collection

The same orthophotos used in the office for photo-interpretation were used in the field, with the addition of topographic themes "overlayed" for enhanced field interpretation. Using Arc/Info's Classify function, each of the previously mentioned topographic themes was "selected out" of the DRG, and then assigned colors appropriate in combination with its paired DOQQ. An AML (Automated Macro Language) was written to automate this process (to be eventually performed for the entire Grand Canyon National Park).

Hard-copy field maps were scaled to utilize the one-meter resolution, with a photo-scale reciprocal of 1:6000. At this scale, four maps were required to provide coverage, with a 20% overlap for polygon transfer. Each map measured approximately 36 inches by 44 inches.

Each of 453 polygons were either visited in the field, or if physically inaccessible, viewed successfully from a vantage point with either 20x50 binoculars or a 20 to 40 power zoom spotting scope.

Equipment and/or guides used for measuring respective fields were as follows: Fuel Model Index -"Aids to Determining Fuel Models For Estimating Fire Behavior"(Anderson, H., 1982); Forest Type - "A Digitized Classification System for the Biotic Communities of North America, with Community and Association Examples for the Southwest" (Brown, Lowe, and Pace, 1979); Crown Height measurements – Suunto Clinometer; and Canopy Closure – A densiometer (hemispheric), a densitometer (GRS - Geographic Resource Solutions), and a "dot grid" (used both on aerial photographs and digital orthophotos). Photographs (slides) were taken at locations representative of the polygon, with the following data on "mug boards" (see Figure 2): Polygon number, date visited, forest type, and fuel model index.

The Crown Bulk Density CBD) field was derived (albeit from field-verified data). An AML was written to calculate CBD per polygon, reflecting BLP Vegetation Classification, Average Crown Height, and Canopy Closure.

Polygon Correction

Where photo-interpreted polygons differed from what was found in the field, polygon delineations were corrected in the field to represent the discrete homogeneous group found there. With each return from the field, field maps were updated in the office, reflecting field corrections (see Figure 7, grouped with Figure 6, following body of text). Approximately 30% of the polygons received some change in delineation. Once all polygons were field verified and corrected, data collected was entered into an Arc/Info environment.

Figure 2. A Photograph with 'Mug Board.'

Data Entry

Data from the Field Data Collection Sheet (see Figure 3, following page) were entered as attributes for each polygon. The assembled database was then checked for accuracy, through a variety of Arc/Info queries designed to capture "no entry" errors and "out-of-range' errors. Arc/Info queries were then used to view exceptions to anticipated patterns (forest types, fuel model index, crown height, vegetation classification). Exceptions were reviewed for correct data entry, and corrected as necessary.

RESULTS

Midway through the Walhalla Plateau Pilot Project, color infra-red (CIR) photography (National High Altitude Photography, captured in 1980) was obtained. Though dated, the superior spectral resolution added a needed dimension. The spectral reflectance from different vegetation (essentially missing from the black-and-white DOQQs) was more apparent, and supported by vegetative classification queries.

Observing an elevational trend in the northern extent of the ponderosa pine forest type, a map was modeled

FARSITE FIELD DATA COLLECTION SHEET

Walhalla Plateau

POLYGON DATA
ID #________________________________
TYPE________________________________

METADATA

DATE OF COLLECTION________________
CREW MEMBERS ________________

POLYGON CHARACTERISTICS

SLOPE (IN PERCENT) ________________
ASPECT (AZIMUTH) ________________

FUEL CHARACTERISTICS

FUEL MODEL INDEX __________________
(See North Rim Fuel Model Characteristics Key)

FOREST CHARACTERISTICS

MEASURMENTS	1st	2nd	3rd
SPECIES	___	___	___
BOTTOM CROWN	___	___	___~~>
BOTTOM TREE	___	___	___~~>
TOP OF TREE/CROWN	___	___	___~~>
SHRUB HEIGHT	___	___	___

TREE DIAMETER CLASSES	%	CrownW
CLASS 1 (<5" DBH)		
CLASS 2 (5 – 11" DBH)		
CLASS 3 (11 – 20" DBH		
CLASS 4 (>20" DBH)		

LOCATION DATA

UTM-N________________________________
UTM-E________________________________
UTM SOURCE__________________________
ELEVATION___________________________

PHOTOGRAPHY DATA

ROLL#/FRAME#________________________
FILM TYPE/SPEED______________________
CAMERA/LENS (mm)____________________

CANOPY COVER CLASS

		PI	DEN	EST
0% (NONE)				
1-20%				
21%-50%				
51%-80%				
81%-100%				

BROWN, LOWE, AND PACE VEG. CLASS.
(See Vegetation Classification Code Sheet)
CODE ____
TYPE ________________________________
% / TYPE_____________________________

CROWN BULK DENSITY (Calculated)_________

CROWN DATA (Average across polygon)

==>HEIGHT TO LIVE CROWN BASE__________

==>TOTAL TREE HEIGHT___________________

➔*Adjusted* Height to Live Crown Base__________

COMMENTS

Figure 3. Field Data Collection Sheet.

on aspect and elevation. With elevational parameters between 6000 and 8230 feet, and slopes between 0 and 20%, a significant portion of the mapped Ponderosa Pine stands were included. The exceptions to this model (pure ponderosa pine stands *not included* within the parameters, and other forest types *included*, were found to occur in adjacent drainages, particularly those with substantial depth (greater than 120 feet). Within such drainages, other forest types were found below a 8230 foot elevation and with north eastern aspect, and Ponderosa stands were found above a 8230 foot elevation with southwestern aspect.

In an elevational band above that of the ponderosa pine forest type, Arc/Info queries made apparent a transitional zone where the mixed conifer forest association intermixed with the ponderosa pine forest type.

The mixed conifer zone extended from the transition one to the upper limits of the Walhalla Plateau Pilot Project area. This zone was most apparent spectrally, in the CIR photography. A bluish hue was visually apparent across a significant portion of the mixed zonifer zone.

DISCUSSION

The use of digital imagery was of significant value in the photo-interpretation of forest type and canopy closure polygons. The ability to vary resolution/scale with “click of the mouse” was a great aid in making judgements on textural cues such as crown size and canopy closure, where shadows permitted, crown shape (Ponderosa crowns characteristically differ from other mixed conifer species) and height. The ability to query a fairly large and complex database, again “with the click of a mouse”, greatly aided data analysis.

Digitally combining the DOQQs and the DRGs was a significant and synergistic enhancement not only for photo-interpretation but for field-verification as well. Orienteering to the various polygons located across the 15,000-acre landscape of the Walhalla Plateau, was done confidently and expeditiously. With a substantial portion of the Walhalla Plateau either essentially flat or dissected by drainages, topographic contours viewed in conjunction with the orthophoto imagery accurately signaled changes in vegetation. This was true particularly in the ponderosa pine forest type and what we labeled as the transition zone, and to a lesser extent in the mixed conifer association, where increased slopes meant higher forest density.

Digital query functions permitted the accurate prediction and subsequent field identification of a ponderosa pine transition zone where mixed conifers were invading open park-like stands, based on elevational (less than 2080 meters a.s.l.) and slope (less than 10%) constraints.

The transition zone, when viewed from a paleontological perspective, takes on a chronological dimension. Ponderosa pines were found at the highest elevations of the North Rim, spatially dispersed and of substantial age (as evidenced by old-growth characteristics such as bark color and appearance, large primary branches, weathered secondary branches, and substantial girth).

This may be a reflection of the paleoclimatic suppositions provided by pollen and midden analysis. Their data supports a migration of all vegetative zones to the North during times of higher moisture and insolation regimes, and a subsequent migration south of vegetative zones responding to a diminished monsoonal influence.

All other things being equal, old-growth ponderosa pine forests are sufficiently well adapted to changing moisture regimes. However, the addition of competing mixed conifer species (allowed to invade what would have been “open, park-like” stands in the transition zone), resulting from this century’s history of wildland fire suppression, is a significant forest health concern. Increased moisture and nutrient demands brought on by invading species, are diminishing old-growth ponderosa pine forest vigor, and increasing stress on a now irreplaceable resource.

CONCLUSION

The Walhalla Plateau, generally representative elevationally of the Grand Canyon’s North Rim, was selected as a pilot project for populating data needed for a fire area growth simulation model (FARSITE). The use of the DOQQ/DRG “TopoPhotos” greatly aided the Walhalla Plateau Pilot Project. The project was started in mid-July 1998, with photo-interpretation completed in late July. Field-verification began in early August 1998 and continued intermittently (with brief office polygon mapping corrections) through mid-September. Data entry and analysis were substantially complete by mid-April 1999, sufficient for initial FARSITE model calibration. Initial FARSITE model runs, without calibration, using weather, wind, and other data to mimic environmental conditions for historic fires, were successful in providing reasonable portrayals (see Figures 8 and 9, following body of text). It is expected that FARSITE model calibrations, once complete across the elevational/vegetational spectrum, will accurately represent both historical and future fire behavior.

With the completion of the Walhalla Plateau Pilot Project, the data will be used in modeling forest types and fuel model indexes for the rest of the forested North and South Rims. Initial comparisons to the 1968 Vegetation Classification are positive, and initial attriibute assignments are under way.

Figure 4. USGS Topographic Maps for Walhalla Plateau/Bright Angel Quads.

Figure 5. USGS Digital Orthophoto Quarter Quads.

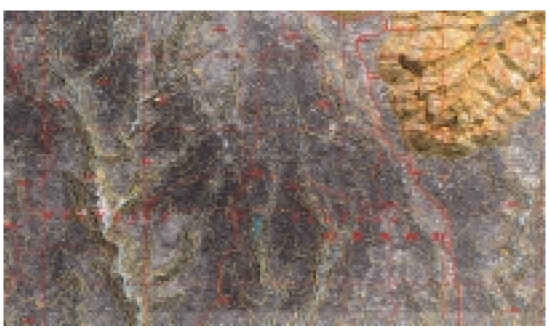

Figure 6. Grand Canyon NP-Science Center GIS DOQQ/DRG "Topo/Photo."

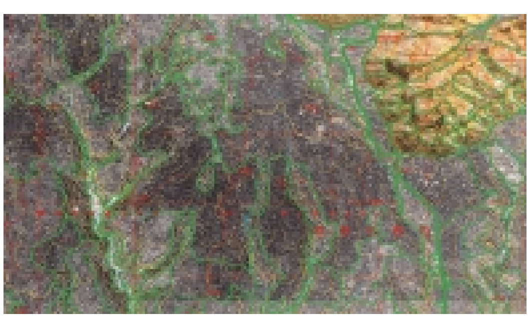

Figure 7. "Topo/Photo" with Fuel Model/Forest Type Polygon Delineation.

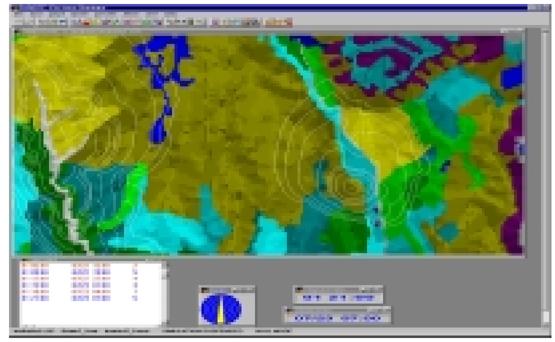

Figure 8. FARSITE Fuel Model Landscape with fire perimeters in two hour time steps.

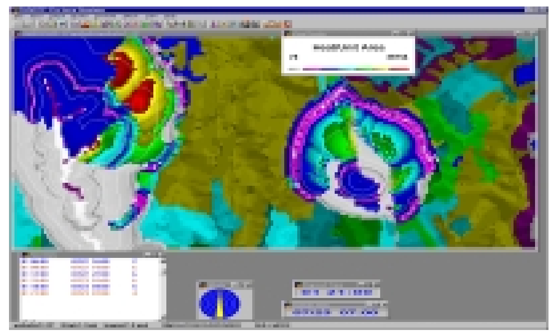

Figure 9. FARSITE Heat/Unit Area Graphic Output.

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BIBLIOGRAPHY

Anderson, H. E. (1982). Aids to determining fuel models for estimation fire behavior. General Technical Report INT-122, 22p. Intermt. For. and Range Exp. Stn., Ogden, Utah 84401.

Cole, K. L. (1981). Late Quaternary environments in the eastern Grand Canyon: Vegetational gradients over the last 25,000. Ph.D. dissertation, University of Arizona, Tucson.

Finney, M. (1997). FARSITETM; Fire area simulator - users guide and technical documentation. Systems for Environmental Management, Missoula MT 59807.

Shafer, D. (1989). The timing of late Quaternary monsoon precipitation maxima in the Southwestern United

States. Ph.D dissertation, University of Arizona, Tucson.

Taush, R. (1999). A summarization created for Pinyon-Juniper Seminar presentation, Grand Canyon National Park AZ.

Weng, C. and S. Jackson. (1999). Late-glacial and Holocene vegetation history and paleoclimate of the Kaibab Plateau, Arizona. Paleogeography, Paleoclimatology, Paleoecology (accepted for publication in 1999).

Wolf, J. and J. Mast. (1998). Fire history of mixed-conifer forests on the North Rim, Grand Canyon National Park, Arizona. Physical Geography, v.19(1), pp. 1-14.